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Study of the elastic and elastooptic properties of $Zn_{1-x}Be_xSe$ mixed crystals by Brillouin scattering method

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ABSTRACT

In this paper we report experimental results concerning the elastic and elastooptic properties of $Zn_{1-x}Be_xSe$ mixed crystals grown by high pressure Bridgman technique. Using Brillouin scattering method some of the elastic and elastooptic constants of $Zn_{1-x}Be_xSe$ crystals with different Be content have been determined at room temperature. It has been revealed that the elastic and elastooptic properties strongly depend on the content of Be.

Keywords: II-VI mixed crystals, $Zn_{1-x}Be_xSe$, elastic and elastooptic properties, Brillouin scattering.

1. INTRODUCTION

There has been a considerable interest in the physical properties of wide gap II-VI mixed crystals containing Mg or Be. $Zn_{1-x}Be_xSe$ solid solution is promising material for construction blue-green laser diodes.[1, 2] These compounds are interesting in the context of control of band gap energies, lattice constants as well as elastic and elastooptic properties. $Zn_{1-x}Be_xSe$ mixed crystals have regular structure, belonging to the T_d^2 space group at room temperature. Recently, some of the physical properties of $Zn_{1-x}Be_xSe$ crystals have been studied using different experimental techniques, such as Raman spectroscopy, photoluminescence and photoacoustic investigations.[3-8] In this paper we report the preliminary study of the elastic and elastooptic properties of $Zn_{1-x}Be_xSe$ mixed crystals with different Be content using Brillouin scattering method.

2. EXPERIMENT

$Zn_{1-x}Be_xSe$ crystals were grown from the melt by the modified high pressure Bridgman method described in details elsewhere.[9] Their composition was determined by chemical wet analysis. The samples used in Brillouin scattering experiment were ground and mechanically polished to the optical quality. They were cut to the sizes of 3mm x 4mm x 5mm, with faces perpendicular to the [100], [010] and [001] directions.

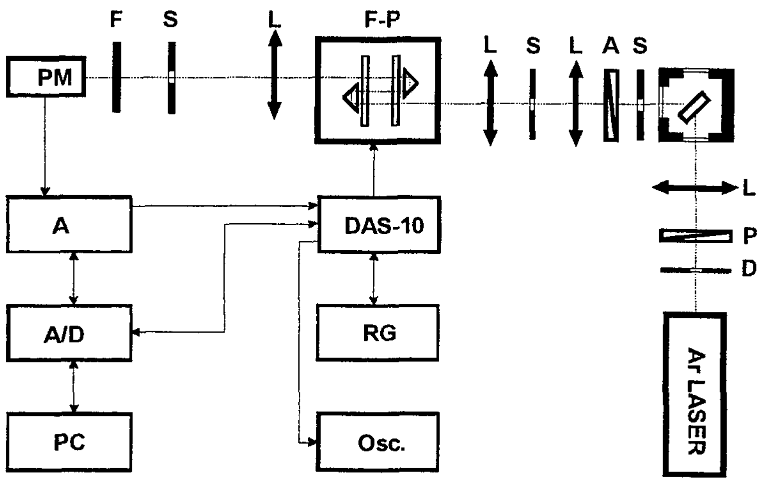

Fig. 1. Schematic picture of the spectrometer used in Brillouin experiment.

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The Brillouin polarized spectra were measured at RT using experimental procedure described elsewhere.[10] The schematic picture of the experimental set-up is presented in Fig.1. An Ar ion laser operating on the 488nm line was used as a source of light. It provided 100mW of cw power during operation on a single mode. The scattered radiation was observed at right angle to the incident beam. As a standard we have employed quartz for which the Rayleigh ratio R_{st} of the longitudinal phonon propagating along [100] direction is known from the literature.[11] The calculation of the Brillouin lines parameters has been performed using curve fitting method. To ensure greater certainty, we made a minimum of 5 separate recordings for each scattering geometry. The estimated error of C_{ij} does not exceed 1% and 5% in the case of p_{ij}.

3. RESULTS AND DISCUSSION

Using Brillouin scattering method we have studied the elastic and elastooptic properties of $Zn_{1-x}Be_xSe$ mixed crystals with different Be content. The scattering geometries used in Brillouin experiment are described in Table 1. For our study we have chosen the longitudinal (L) and transverse (T_2) acoustic phonons propagating in $[01\bar{1}]$ direction.

The data which served as a basis for the determination some of the elastic and elastooptic constants of of $Zn_{1-x}Be_xSe$ mixed crystals are listed in Table 2. The phase velocity for longitudinal and transverse acoustic modes deduced from Brillouin spectra are also presented in Table 2.

The typical Brillouin spectra of $Zn_{1-x}Be_xSe$ mixed crystals with different Be content obtained for longitudinal (L) and transverse (T_2) acoustic phonons propagating in $q = [01\bar{1}]$ direction at room temperature are presented in Fig. 2.

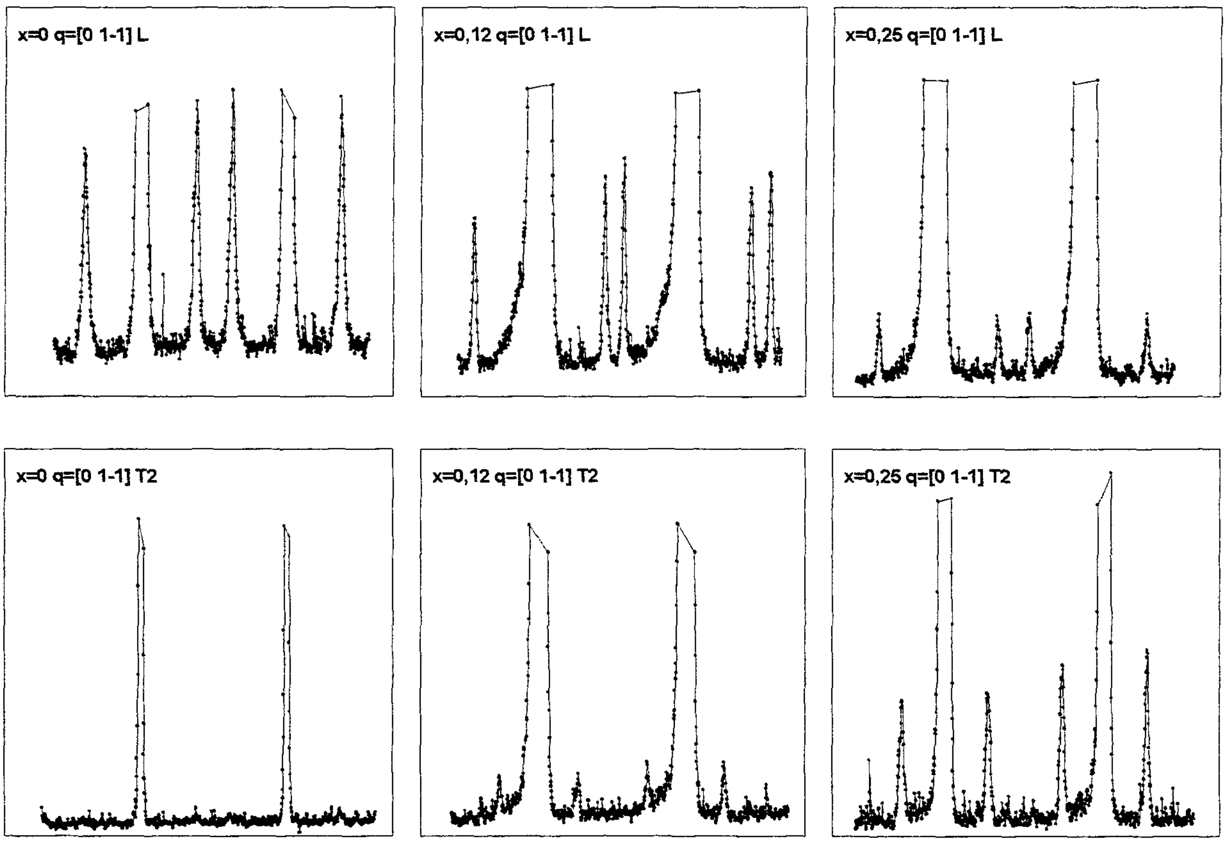

Fig. 2. The Brillouin spectra of $Zn_{1-x}Be_xSe$ mixed crystals with different Be content obtained for the acoustic phonon propagating in $[01\bar{1}]$ direction.

Table 1. Scattering geometries used in Brillouin experiment

$k_i = [001]$ $k_s = [010]$	q	L $u = [01\bar{1}]/\sqrt{2}$ $\rho V^2 = (C_{11}+C_{12}+2C_{44})/2$	T_2 $u = [100]$ $\rho V^2 = C_{44}$
$d_i = [001]$ $d_s = [001]$	$[01\bar{1}]/\sqrt{2}$	p_{12}^2	0
$d_i = [001]$ $d_s = [110]/\sqrt{2}$	$[01\bar{1}]/\sqrt{2}$	0	$p_{44}^2/2$

Table 2. The data which served as a basis for determination some of the elastic and elastooptic constants. of $Zn_{1-x}Be_xSe$ mixed crystals.

X	ρ [g/cm³]	N	V_L [m/s]	V_{T_2} [m/s]
0	5.269	2.784	4422	2418
0.12	5.194	2.760	4557	2727
0.25	5.102	2.734	4179	2851

3.1. Study of the elastic properties

$Zn_{1-x}Be_xSe$ mixed crystals crystallize in the regular structure (T_d^2 space group). They have three independent elastic constants: $C_{11} = C_{22} = C_{33}$, $C_{44} = C_{55} = C_{66}$, $C_{12} = C_{13} = C_{23}$.[12]

Velocities V_j of the transverse and longitudinal acoustic phonons propagating along $[01\bar{1}]$ direction in $Zn_{1-x}Be_xSe$ mixed crystals with different Be content were determined first. These velocities were deduced from the measured frequency shift $\Delta\omega_B$ using the Brillouin equation, which in the case of 90^0 scattering geometry takes the form:

$$\Delta\omega_B = Vj\,\omega_i\,[(n^i)^2 + (n^s)^2 - 2\,n^i\,n^s\cos\Theta]^{1/2}/c \qquad (1)$$

where ω_i is the frequency of the incident light, n^i and n^s are the refractive indices for the incident and scattered light, respectively and Θ is the angle between the incident and scattered beams.

The velocities were then used to estimate the elastic constants C_{ij}. The elastic constants can be determined from the solution of the equation of motion, which is given by:

$$|\,C_{ijkl}q_j q_k - \rho V^2\delta_{il}\,| = 0 \qquad (2)$$

Here q_j, q_k are the direction cosines of the phonon wave-vector **q**, ρ is the density of the crystal and C_{ijkl} are the elastic constants.

Our study enabled us to estimate the values of the $(C_{11} + C_{12} + 2C_{44})/2$ and C_{44} elastic constants. Obtained results are presented in Fig.3a. It can be seen that the elastic properties of $Zn_{1-x}Be_xSe$ mixed crystals strongly depend on Be content. The value of the $(C_{11} + C_{12} + 2C_{44})/2$ decreases, while the value of C_{44} elastic constant increases with the increase of Be content.

3.2. Study of the elastooptic properties

$Zn_{1-x}Be_xSe$ mixed crystals belonging to the regular structure (T_d^2 space group) have three independent elastooptic constants: $p_{11} = p_{22} = p_{33}$, $p_{44} = p_{55} = p_{66}$, $p_{12} = p_{13} = p_{23}$.[12] In order to determine the elastooptic properties of $Zn_{1-x}Be_xSe$ mixed crystals with different Be content, we used a substitution technique proposed by Cummins and Shoen [11], and developed by Nelson and Lax.[13] In this method the Brillouin spectrum of the crystal under study is compared to that of a standard scatterer whose

Rayleigh ratio R_{st} is known. If I is the observed (integrated) intensity of the Brillouin line in the sample spectrum while I_{st} is the intensity of the Brillouin line in the spectrum of the standard scatterer, the Rayleigh ratio R of the sample is given by:

$$R=R_{st}\,(I / I_{st}) = R_{st}\,J \tag{3}$$

Using Nelson and Lax's approach [13], the formula for Rayleigh ratio can be written as:

$$R = (\pi^2 kT/2\,\lambda^4)\,BCF \tag{4}$$

where, for 90-degree scattering geometry, C is given by :

$$C = (n^i n^s)^3 \cos\delta^i \cos\delta^s / \rho V^2 \tag{5}$$

and F is given by :

$$F = \left| d_m^s p_{mnkl} d_n^i u_k q_l \right|^2 \tag{6}$$

In Eqs (4) - (6): B is geometric factor which is assumed to be equal for the unknown sample and the standard, $\delta^{i,s}$ is the angle between the Poynting vector and the wave-vector of the incident/scattered beam, d_m^s, d_n^i describe the polarization vector of the scattered and incident waves, respectively, $n^{i,s}$ is the appropriate refractive index, p is the effective elastooptic tensor, u_k is the component of the atomic displacement vector and q_l is the component of the phonon wave-vector.

The appropriate elastooptic constant p_{ij} can be determined from equation:

$$F / F_{st} = J\,C_{st} / C \tag{7}$$

From our study the values of p_{12} and p_{44} elastooptic constants were determined. The obtained results are presented in Fig.3b. It can be seen that in the investigated range of composition the elastooptic properties of $Zn_{1-x}Be_xSe$ mixed crystals depend on Be content noticeably. The value of the p_{12} decreases, while the value of p_{44} elastooptic constant increases with the increase of Be content.

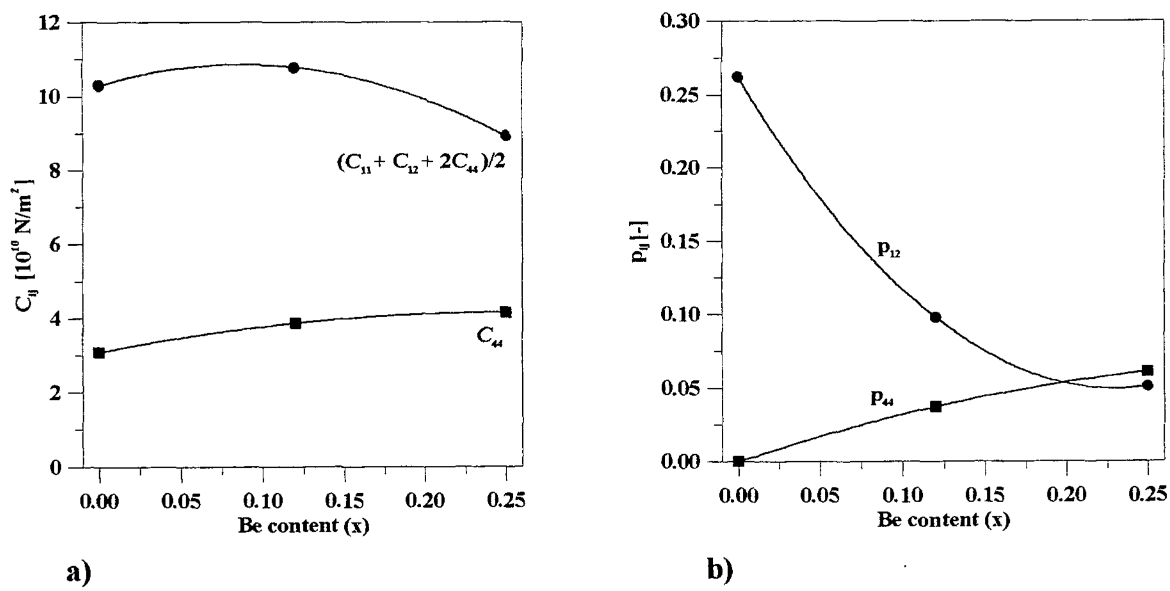

Fig. 3. The dependence of the : a) - $(C_{11} + C_{12} + 2C_{44})/2$ and C_{44} elastic constants and b) - p_{12} and p_{44} elastooptic constants for $Zn_{1-x}Be_xSe$ mixed crystals as a function of Be content obtained for acoustic phonon propagating in direction $[01\bar{1}]$ at room temperature.

4. CONCLUSIONS

Using Brillouin scattering measurements some of the elastic and elastooptic constants have been determined. It has been revealed, that the elastic and elastooptic properties of $Zn_{1-x}Be_xSe$ crystals strongly depend on Be content. However, the nature of this phenomenon is still not well recognized. Its qualification needs further Brillouin scattering study and this is now in progress.

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